Towards 5G Internet of Things

DVCon Europe 2017, Munich, October 17, 2017
Sabine Roessel, Senior Principal Engineer, Intel Corporation
5G is more than just the next generation mobile communication standard ...
Key Elements of 5G New Radio

Flexible OFDM numerology with 8 different subcarrier spacings around LTE’s 15kHz

New spectrum: mmWave sub-1GHz

BS & UE Beamforming built into the 5G standard

New channel coding, namely Polar codes
5G Use Cases in 3GPP

**Enhanced Mobile Broadband (eMBB)**
- High peak throughput
- High spectral efficiency
- High capacity
- Mobility

**Massive Machine-Type Communication (mMTC)**
- Energy efficiency
- Massive #connections
- Very large coverage

**Ultra-Reliable Low Latency Communication (URLLC)**
- Ultra-high reliability
- Ultra-low latency

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Sabine Roessel, Intel Corporation: "Towards 5G Internet of Things " Invited Talk for 5G Special Interest Session @ DVCon Europe 2017, Munich
Towards 5G Internet of Things

50 BILLION
Things¹²

1.5 GIGABYTE
Internet user IP data per day³

4 TERABYTE
Self-driving car IP data per day³

1 PETABYTE
Connected factory IP data per day³

2.3 ZETTABYTE
Annual global IP data³

Cellular Connectivity

THINGS

Network

DATA CENTER CLOUD

01010101101100101010010100101101101001010100101

1) IDC 2016: 212 sensors in 2020, 1:n thing to sensor ratio varies with use case
2) 4Q15 Gartner connected devices forecast: installed base 20 Bn devices in 2020
3) 2016 Cisco VNI Global IP Traffic Forecast for 2020: 1 Zettabyte = 1 Zetabyte
# LTE Massive MTC and NB-IoT

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Cat.1 (Rel.8)</th>
<th>Cat.M1 (eMTC) (Rel.13)</th>
<th>Cat.NB1 (NB-IoT) (Rel.13)</th>
<th>Cat. M2 (FeMTC) (Rel.14)</th>
<th>Cat.NB2 (eNB-IoT) (Rel.14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>20MHz</td>
<td>1.4MHz</td>
<td>200kHz</td>
<td>Up to 5 MHz</td>
<td>200kHz</td>
</tr>
<tr>
<td>Deployments/HD-FDD</td>
<td>LTE channel / No HD-FDD</td>
<td>Standalone, in LTE channel / HD-FDD preferred</td>
<td>Standalone, in LTE channel, LTE guard bands, HD-FDD</td>
<td>Standalone, in LTE channel / HD-FDD, FD-FDD, TDD</td>
<td>Standalone, in LTE channel, LTE guard bands, HD-FDD, TDD</td>
</tr>
<tr>
<td>MOP</td>
<td>23dBm</td>
<td>23dBm/20dBm</td>
<td>23dBm/20dBm</td>
<td>23dBm/20dBm</td>
<td>23dBm/20dBm/14dBm</td>
</tr>
<tr>
<td>Rx ant / layers</td>
<td>2/1</td>
<td>1/1</td>
<td>1/1</td>
<td>1/1</td>
<td>1/1</td>
</tr>
<tr>
<td>Coverage, MCL</td>
<td>145.4dB DL / TBD DL 140.7dB UL</td>
<td>155.7dB</td>
<td>164dB</td>
<td>155.7dB (at 23dBm)</td>
<td>Deep coverage: 164dB</td>
</tr>
<tr>
<td>Data rates (peak)</td>
<td>DL: 10 Mbps UL: 5 Mbps</td>
<td>~800 Kbps (FD-FDD) 300/375 Kbps DL/UL (HD-FDD)</td>
<td>DL/UL: 4 Mbps FD-FDD@5MHz</td>
<td>TBS: 2536 TBS: 1352/1800 (2 HARQ)</td>
<td></td>
</tr>
<tr>
<td>Latency</td>
<td>Legacy LTE: &lt;1s</td>
<td>~ 5s at 155dB</td>
<td>&lt;10s at 164 dB</td>
<td>At least the same as Cat. M1</td>
<td>At least the same as Cat. NB1</td>
</tr>
<tr>
<td>Mobility</td>
<td>Legacy support</td>
<td>Legacy support</td>
<td>Cell selection, re-selection only</td>
<td>Legacy support</td>
<td>More mobility vs. Cat. NB1</td>
</tr>
<tr>
<td>Positioning</td>
<td>Legacy support</td>
<td>Partial support</td>
<td>Partial support</td>
<td>OTDOA legacy PRS, freq. hopping</td>
<td>50m H target, new PRS for OTDOA</td>
</tr>
<tr>
<td>Voice</td>
<td>Yes (possible)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Power saving</td>
<td>DRX</td>
<td>eDRX, PSM</td>
<td>eDRX, PSM</td>
<td>eDRX, PSM</td>
<td>[eDRX, PSM]</td>
</tr>
<tr>
<td>Battery life</td>
<td>Traffic model</td>
<td>10 years</td>
<td>10 years</td>
<td>10+ years</td>
<td>10+ years</td>
</tr>
</tbody>
</table>

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NB-IOT and 5G Massive MTC (mMTC)
Key Performance Requirements

10x connection density

10^6 devices per sqkm in urban environment

>164 dB coverage

164dB MCL @160 bps

>10 years battery life

200 Byte UL per day @164dB MCL

<10 sec latency

20 Byte UL packet from deep sleep @164dB MCL

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1: Refer to 3GPP TR 38.913 for details.
2: Valid for 5G, NB-IOT achieves 100K – 200K (c.f. 3GPP TR 45.820)
3: MCL: Maximum Coupling Loss
4G and 5G Energy Saving Techniques

3GPP Rel.12 PSM  Max time in Power Saving Mode (device unreachable by network): ~13 days
3GPP Rel.13 I-eDRX Max Idle Mode eDRX: ~3 hours
3GPP Rel.13 C-eDRX Max Connected Mode extended Discontinuous RX (eDRX) cycle: ~9 seconds
3GPP Rel.15 WUR Wake-up signal for wake-up receiver (WUR)

Illustrative: scaling of time (x-axis) and power (y-axis) do not represent realistic ratios.
5G Ultra-Reliable Low Latency Comms (URLLC) Key Performance Requirements (TR 38.913)

0.5ms U-plane latency

<table>
<thead>
<tr>
<th>Successful delivery of DL or UL packet from L2/L3 ingress to L2/L3 egress point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>99.999% reliability</strong>&lt;sup&gt;2,3&lt;/sup&gt;</td>
</tr>
<tr>
<td>General: 32 Byte packet @1ms U-plane latency</td>
</tr>
<tr>
<td>5G V2X: 300 Byte packet @3ms ...10ms U-plane latency</td>
</tr>
<tr>
<td><strong>accurate position</strong>&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>5G V2X positioning accuracy&lt;sup&gt;5&lt;/sup&gt;: lateral &lt;0.1m longitudinal &lt;0.5m</td>
</tr>
</tbody>
</table>

1: For URLLC (= Ultra-Reliable Low Latency Communications) use cases
2: Percentage of packets successfully delivered out of packets sent and within a service-specific time constraint; U-plane: user plane, DRX: discontinuous reception, SDU: Service Data Unit
3: For URLLC and eV2X (enhanced Vehicle-to-Everything) use cases
4: For mMTC (massive Machine-Type Comms), URLLC, and eV2X use cases; GNSS: Global Navigation Satellite Systems, OTDOA/UTDOA: Observed/ Uplink Time Difference of Arrival
5: TR 22.886
5G Automotive Use Cases Trigger Low Latency and High Reliability Requirements (TR 22.886)

**Platooning**
- Automated cooperative driving for short distance grouping
- Info sharing for limited/fully automated platooning

**Advanced Driving**
- Cooperative Collision Avoidance (CoCA)
- Emergency Trajectory Alignment (ETrA)
- Info sharing for semi-/fully automated driving

**Extended Sensors**
- Sensor sharing
- Collective environment perception

**Remote Driving**
- Operation of remote vehicle
### Industrial IoT Requirements

<table>
<thead>
<tr>
<th>Category</th>
<th>Max latency</th>
<th>Reliability</th>
<th>Message or Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INDUSTRIAL AUTOMATION</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process automation (VDE, ZVEI)</td>
<td>1/2 cycle time: cycle time = 1ms ... 1s</td>
<td>BLER: 10^{-5}</td>
<td>30 ... 1500bytes</td>
</tr>
<tr>
<td>Industrial process automation (TR22.862)</td>
<td>100ms ... 1s</td>
<td>Packet loss rate &lt;10^{-5}</td>
<td>&lt; 100bytes per message</td>
</tr>
<tr>
<td>Factory automation (VDE, ZVEI)</td>
<td>1/2 cycle time: cycle time &lt; 1ms</td>
<td>BLER: 10^{-5}</td>
<td>&lt; 30bytes</td>
</tr>
<tr>
<td>Industrial factory automation w/ CL control (TR22.862)</td>
<td>&lt; 1ms ... 10ms</td>
<td>Packet loss rate: 10^{-9}</td>
<td>&lt; 50bytes</td>
</tr>
<tr>
<td><strong>/ROBOTICS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robot finger to robot control short-range</td>
<td>&lt; 1ms</td>
<td></td>
<td>24Gbps</td>
</tr>
<tr>
<td>Robot to network, free robot from cable (TR22.862)</td>
<td>&lt; 1ms</td>
<td>Packet loss rate: 10^{-9}</td>
<td></td>
</tr>
<tr>
<td>Collaborative robots in manufacturing (NGMN WP)</td>
<td>&lt; 1ms</td>
<td>Transaction failures: 10^{-9}</td>
<td></td>
</tr>
<tr>
<td><strong>/AUGMENTED REALITY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual console AR to control manufacturing</td>
<td>&lt; 8ms</td>
<td></td>
<td>Order of Mbps</td>
</tr>
<tr>
<td><strong>SMART GRID</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trips and blocking, inside substation (IEC61850)</td>
<td>&lt;= 3ms</td>
<td></td>
<td>10s of bytes</td>
</tr>
<tr>
<td>Release status changes, between controllers in one substation or between substations (IEC61850)</td>
<td>&lt;= 10ms</td>
<td>Packet loss rate: 10^{-4}</td>
<td>80 ... 1000bytes</td>
</tr>
<tr>
<td>Substation protection and control (TR22.862)</td>
<td>&lt; 1ms (e2e)</td>
<td></td>
<td>12.5Mbps</td>
</tr>
<tr>
<td>Smart grid system w/ distributed sensors (TR22.862)</td>
<td>&lt; 8ms (one trip)</td>
<td>99.999%</td>
<td>200 ... 1521bytes</td>
</tr>
</tbody>
</table>
The Low E2E Latency Challenge

1) User plane latency is the time it takes to successfully deliver an application layer packet or message from the radio protocol layer 2/3 service data unit (SDU) ingress point to the radio protocol layer 2/3 SDU egress point (TR 38.913). Modem processing times, (radio) transmission time interval (TTI) and an averaged contribution from Hybrid Automatic Repeat Request (HARQ) retransmissions contribute to the user plane latency.

2) RTT is the Round Trip Time including user plane latency contributions, application processing times and transport network delays.
The Low E2E Latency Challenge – 5G Employs Mobile Edge Computing (MEC)

1) For example: comparing fiber optics contributions to round trip times (assuming zero processing delay in transport and core network nodes) for Mobile Edge application server at 1km from/to base station: ~0.01ms
And for distant Cloud application server at 10,000km from/to base station: ~100ms

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The Low E2E Latency Challenge – 5G Significantly Reduces Radio I/F (U-Plane) Latency

For example: typical 5G parameters of 60kHz subcarrier spacing and a 2 OFDM symbol transmission time interval (TTI) allow for a user plane latency of significantly less than 1ms.

1) For example: typical 5G parameters of 60kHz subcarrier spacing and a 2 OFDM symbol transmission time interval (TTI) allow for a user plane latency of significantly less than 1ms.
How 5G Enables Extremely Low U-Plane Latency

- **3.75kHz**: 1ms slot (former LTE 1ms subframe)
- **7.5kHz**: 0.5ms slot
- **15kHz**: 125µs slot
- **30kHz**: 0.5ms slot
- **60kHz**: 1ms slot
- **120kHz**: 125µs slot

**OFDM symbol 5G (120kHz subcarrier spacing) vs. LTE**: 1/8

- 2 OFDM symbol mini-slot vs. 14 OFDM symbol slot: 1/7
5G Energy Efficiency Key Performance Requirements (TR 38.913)

UE energy efficiency

Capability of a UE to sustain a much higher mobile broadband data rate while minimizing UE modem energy consumption.

It is a qualitative KPI.

Network energy efficiency

Capability to minimize radio access network energy consumption while providing a much better area traffic capacity.

Both qualitative and quantitative\(^1\) KPI are proposed.

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1: Quantification based on:
(1) Use of IMEC model
(2) Energy Efficiency evaluated by system level simulations at least in 2 deployment scenarios: one coverage limited environment (ex.: Rural) and one capacity limited environment (ex.: Dense Urban)
(3) Recommendation to consider 3 (network traffic) load levels
(4) Cooling system impact on EE not discussed in 3GPP RAN
(5) Evaluation methodology based on inspection as baseline and system level evaluation if necessary
# The Sustainable Smart City

<table>
<thead>
<tr>
<th>Smart City Segments¹</th>
<th>Traffic Transport Logistics</th>
<th>Buildings</th>
<th>Manufacturing</th>
<th>Energy &amp; Lighting</th>
<th>Water, Air, Waste</th>
<th>Commerce &amp; Social Services</th>
<th>5G IoT &amp; ICT = Smart e-Services</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smart Mobility</td>
<td>Smart Buildings</td>
<td>Smart Factory</td>
<td>Smart Grid</td>
<td>Smart Environment</td>
<td>e-Services</td>
<td></td>
</tr>
</tbody>
</table>

ICT and Internet of Things Electricity Demand

- Upper bound ICT electricity demand (iso-energy-efficiency)
- Estimated ICT electricity demand
- Lower bound ICT electricity demand /3/

/3/: Based on „Energy efficiency in 5G networks“ by Aarne Mämmelä, VTT Technical Research Centre of Finland; IFIP
5G Internet of Things – Wrap-Up

• 5G is more than the next generation mobile communication standard
• 5G for sure creates challenges for chipset and network equipment vendors
• 5G key performance indicators reach beyond "galactic" mobile broadband data rates: massive connectivity, device and network energy efficiency, high reliability, and lowest e2e latency
• 5G enables the Internet of Things ...
• "Investments [...] in modern information and communication infrastructure fuel sustainable economic growth, a high quality of life, with a wise management of natural resources, through participatory governance.” Caragliu, Del Bo, Nijkamp about Smart Cities, 2011